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Fully differential QCD corrections to single top quark final states

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A new next-to-leading order Monte Carlo program for calculation of fully differential single top quark final states is described and first results presented. Both the s- and t-channel contributions are included.

1. Introduction

The electroweak production of single top quarks, despite being smaller in rate than it's strong interaction counterpart — $t\bar{t}$ pair production, offers many physics possibilities for the Tevatron Run II and the LHC. Direct measurement of $|V_{tb}|^2$ and sensitivity beyond the Standard Model are two examples [1]. It is also a background to some signals for the Higgs boson and various types of new physics. Total rates for the s- and t-channel production processes have been calculated[2,3] to next-to-leading order (NLO) in perturbative QCD.

Herein we give first results in our ongoing effort to calculate fully differential NLO QCD corrections to single top quark final states at hadron colliders. The advantages of calculating cross sections to NLO in a fully differential manner are well known in general. For example, only at NLO does a jet definition enter non-trivially. Additionally, systematic errors are always reduced when one can predict the cross in the experimentally visible region, as opposed to extrapolating the measured cross section to the full phase space to get a total rate.

2. Method

The results presented below are from a calculation performed using the phase space slicing method [4]. Briefly, two cutoffs are used to isolate the regions containing soft and collinear singularities from the remainder of the three-body phase space. The three-body squared matrix elements are integrated over these singular regions analytically. The soft singularities cancel upon addition of the virtual contributions, and the remaining collinear singularities are factorized into the parton distributions. The integrations over the singularity-free portions of the three-body phase space are performed using Monte Carlo methods. When all of the contributions are combined at the histogramming stage the various cutoff dependences cancel, since the cutoffs merely mark the boundary between the regions where the integrations were performed using analytic or Monte Carlo methods.

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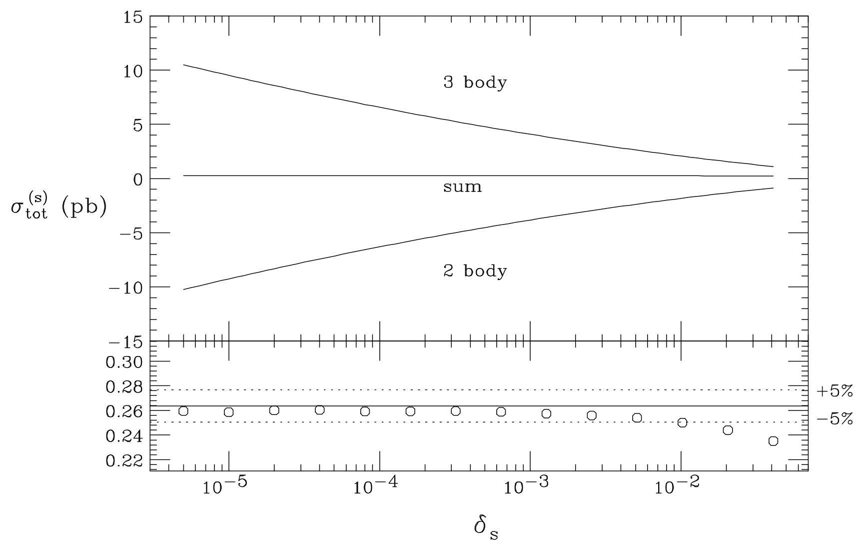

Fig. 1. The next-to-leading order contribution to the single-top-quark total cross section via the s-channel process. The two- and three-body contributions, together with their sum, are shown as a function of the soft cut-off δ_s. The bottom enlargement shows the sum (open circles) relative to $\pm 5\%$ (dotted lines) of the analytic result (solid line).

3. Results

Using the method described in the previous section we have calculated the corrections to both s- and t-channel single-top-quark production. Due to space limitations only s-channel results will be shown, and those only superficially. Full details are forthcoming [5].

A necessary check on the results based on this method is that infrared-safe physical observables are independent of the cut-offs used to delineate phase space, provided they are chosen small enough. The total cross section is an infrared-safe observable. Shown in Fig. (1) is the NLO *correction* to the total cross section as a function of the soft cut-off δ_s summed over t and $\bar{t}$ final states for the s-channel production process compared with the known result[2] using CTEQ4M[6] parton distribution functions at a $\sqrt{S} = 2$ TeV proton-antiproton machine. The mass factorization and renormalization scales are taken to be $\mu_f = \mu_r = m_{\rm top} = 175$ GeV. The mass of the bottom quark was neglected and that of the W gauge boson was taken to be 80.4 GeV. The Monte Carlo result for the NLO correction is within one percent of the analytical result of 0.264 *pb* for $\delta_s < 10^{-3}$ implying better than a third of a percent agreement for the full NLO result of 0.922 *pb*.

Shown in Fig. (2) are the leading order (lower curves) and full next-to-leading order (upper curves) rapidity (left) and transverse momentum (right) distributions of the top quark produced via the s-channel process. These curves were made using the same inputs as above, and no other cuts were applied. These results are also cut-off independent, as expected. Taking the ratio of NLO and LO the corrections

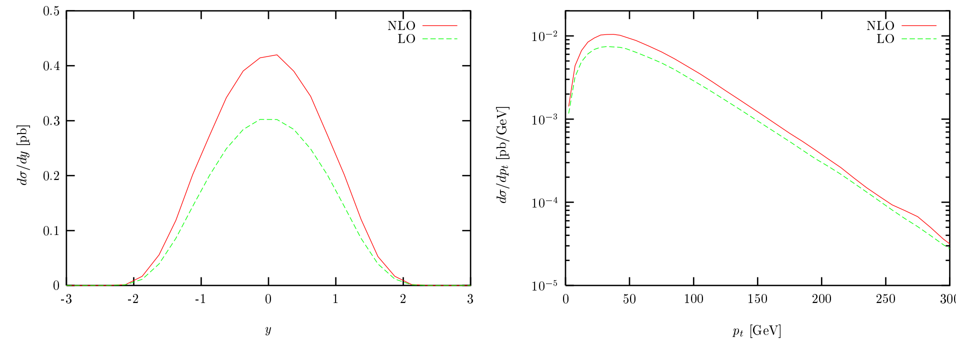

Fig. 2. Leading (lower curves) and full next-to-leading (upper curves) order rapidity (left) and transverse momentum (right) spectra for the top quark produced via the s-channel process.

are observed to be relatively independent of the rapidity and transverse momentum of the top quark, a somewhat atypical, but serendipitous (from the event generation point of view), situation that warrants further investigation.

In conclusion, we have performed a fully differential calculation of QCD corrections to electroweak production of single top quarks. The method used allows for jet definitions and experimental cuts. The corresponding computer code passes the necessary check of reproducing the previously known total rate. First examination of the rapidity and transverse momentum of the top quark shows the corrections to be flat relative to leading order. Additional phenomenological studies are in order. Further work is in progress on the corrections to $t - b - jet$ final states which will give a comprehensive set of tools for studying single-top-quark production at future hadron-hadron colliders.

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